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Use of magnetic measures to assess soil redistribution following deforestation in hilly region

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ABSTRACT

Limited information is available about the use of magnetic susceptibility property to determine soil redistribution in hilly areas of the semi-arid regions. This study was conducted to evaluate the use of magnetic properties to determine soil redistribution along a hill slope following deforestation. The study area is located in the Quaternary hilly region of Lordegan district in west Iran. Ten transects were established in two land uses that included natural Querqus forested and cultivated lands. Soil samples were collected at different positions along the slope and magnetic properties (χlf, χhf, SIRM, ARM, and χfd) and selected physico-chemical properties were determined. The results (based on the χfd, SIRM/ARM) showed that the magnetic susceptibly in the calcareous materials is pre-dominantly derived during the pedogenic processes and the superparamagnetic particles which were transported to lower positions of hill slope following deforestation. The results confirmed that this methodology could be applied for monitoring soil redistribution along the slope in calcareous hilly areas in the semi-arid regions.

1. Introduction

Accelerated soil erosion on cultivated lands is a serious global problem, especially in hilly regions with undulating topography. Soil erosion not only results in on-site soil degradation, but also leads to off-site problems related to downstream sedimentation area as well as surface and ground water pollution. Soil erosion reduces productivity as a result of loss of organic matter, plant nutrients and reduced soil depth (Abbaszadeh Afshar et al., 2010).

Several techniques have been proposed and applied to estimate soil erosion and deposition (Sac et al., 2008). The conventional, empirical techniques for estimating the soil erosion such as the Pacific Southwest Inter-Agency Committee (PSIAC) method have been widely used at the watershed scale in Iran; and the method has predicted a soil erosion rate of 13.72 t ha^{-1} yr^{-1} for lands with steep slopes in the Zagrous region, Iran under rain-fed cropping systems (Abbaszadeh Afshar et al., 2010). Abbaszadeh Afshar et al. (2010) applied the Cs-137 technique in the Ardal district of Iran using a simplified mass balance model, reported a gross erosion rate of 29.8 t ha^{-1} yr^{-1} and a net soil deposition of 21.8 t ha^{-1} yr^{-1}; hence, a net soil loss of 8 t ha^{-1} yr^{-1} and a sediment delivery ratio of 27%.

Magnetic susceptibility, the ratio of induced magnetization to an applied magnetic field, is a function of strongly magnetic particle concentration, grain size, grain shape and mineralogy (Thompson and Oldfield, 1986). The most easily and commonly measured property of soils is its volumetric or mass magnetic susceptibility. Field measurements of volume magnetic susceptibility are typically reported in dimension volume units ($\times 10^{-5}$), whereas laboratory measurements of mass susceptibility are reported in mass based units ($\times 10^{-8}$ m^3 kg^{-1}). The soil sample to be tested is placed inside an electromagnetic coil and the induced magnetic field is measured (Mullins, 1977).

Magnetic susceptibility measurements can serve a variety of applications including the determination of changes in soil forming processes and the dominant ecological conditions (Singer et al., 1996), the study of parent material effects (e.g. Lu, 2000), understanding sedimentation processes (Caitcheon, 1993), soil drainage conditions (Kravchenko et al., 2002; Mathe and Leveque, 2003), soil pollution(e.g. Blundell et al., 2009; Karimi et al., 2011), and even the separation and identification of soil delineations (Grimley et al., 2004).

Magnetic susceptibility has been identified and used for monitoring soil redistribution at landscape scale as a rapid and cost-effective approach. Hutchinson (1995) determined sediment source and erosion status of a British upland catchment by combined use of magnetic and radiometric measurements. de Jong et al. (1998) in a

Abbreviations: SOM, Soil organic matter; CCE, Calcium carbonate equivalent; Min, Minimum; Max, Maximum; S.D, Standard deviation; Skew, Skewness; Kurt, Kurtosis; C.V, Coefficient of Variation; ANOVA, Analysis of variance; χlf, Magnetic susceptibility at low frequency; χhf, Magnetic susceptibility at high frequency; SIRM, Saturation isothermal remanent magnetization; ARM, Anhysteritic remnanet magnetization; χ_{fd}, Frequency dependence; NF, Natural forest; CL, Cultivated land; SU, Summit; SH, Shoulder; BS, Back slope; FT, Foot slope; TS, Toe slope; XRD, X-ray diffraction.

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study of Canadian prairies, attempted to quantify post and pre-1960 soil erosion in a small cultivated basin near Saskatoon, Canada and reported high variability in χ with depth at the sites under erosion. Also, the upper and middle positions along the slope had a much higher χ than in the lower slope area.

Royall (2007) evaluated the use of mineral-magnetic data to determine spatial distribution of long-term cumulative soil loss from agricultural fields and compared the data with results obtained using the revised universal soil loss equation (RUSLE). The results showed that the RUSLE and magnetism models were in agreement. RUSLE under predicted denudation relative to the results obtained using the magnetism-model in the over upper slopes, but over predicted denudation in the lower slopes. Sadiki et al. (2009) found that the effects of land use seemed a key factor influencing the distribution of magnetic susceptibility in the soil profiles.

In the Querqus forest in western Iran, the anthropogenic pressure to change natural forest into cultivated land is significant and as a result soil erosion has increased spectacularly (Abbaszadeh Afshar et al., 2010).

The main objectives of this research were to: 1) employ the variation in the soil magnetic susceptibility to determine soil redistribution along the slope in hilly regions under different land uses and 2) examine the effects of slope positions on the variability in magnetic susceptibility, and to relate the magnetic susceptibility measurements to soil characteristics at different slope positions.

2. Materials and methods

2.1. Site description

This study was conducted in hilly regions of uplands Lordegan watershed located in western Iran (Fig. 1). The study area is located within 50° 12 to 50° 37 E longitude and 31° 58 to 32° 03 N latitude. The mean elevation of the area is approximately 1860 m above the sea level. The mean annual temperature and precipitation at the site is 15 °C. and 600 mm, respectively. The hill slopes of the area have been developed by extensive dissection of sedimentary Quaternary deposits. The soils of the study area are dominantly classified as Fine loamy, mixed, thermic, Typic Haploxerolls and Fine, mixed, thermic, Typic Calcixerepts (Soil Survey Staff, 2006).

2.2. Soil sampling

The physiographic factors examined in this study were the slope position and land use. Two major land uses including natural forest (NF) and deforested cultivated land (CL) and five slope positions including summit (SU), shoulder (SH), back slope (BS), foot slope (FS) and toe slope (TS) were chosen. Forest degradation and cultivation on these sloping areas have started 50 years ago.

Based on the two above mentioned physiographic factors, ten transects were established (F1–F5 for natural forest land use and C1–C5 for cultivated land). To cover the main soil characteristics under five slope positions and land uses, a soil sampling scheme was established on the transects. In each sampling point, undisturbed soil cores were collected using a 5.5 cm diameter corer lined with a clare plastic sleeve from the upper 30 cm soil surface. The cores were transported to the laboratory, and cut into 6-cm segments. Samples were air-dried and passed through a 2 mm sieve for chemical, physical and magnetometric analyses. Some undisturbed soil samples from the subsurface were collected using Kubiena sampler, for micromorphological studies.

2.3. Laboratory analyses

Soil particle size distribution and texture was obtained by the Bouyoucos hydrometer method (Gee and Bauder, 1986). Soil organic matter (SOM) was determined using a wet combustion method (Nelson and Sommers, 1982). Calcium carbonate equivalent (CCE) was calculated using a titrimetric method (Burt, 2004). The dithionite–citrate bicarbonate method (#84-010 in Sheldrick, 1984) was used to measure Fe_d and acid ammonium oxalate (#84-011 in Sheldrick, 1984) for Fe_o. The ratio of Fe_o/Fe_d was used as an indicator of the soil development.

A set of environmental magnetic parameters including magnetic susceptibility at low frequency (χlf), saturation isothermal remanent magnetization (SIRM), and anhyteretic remanent magnetization (ARM) were also determined. Magnetic susceptibility (χ) was measured at low

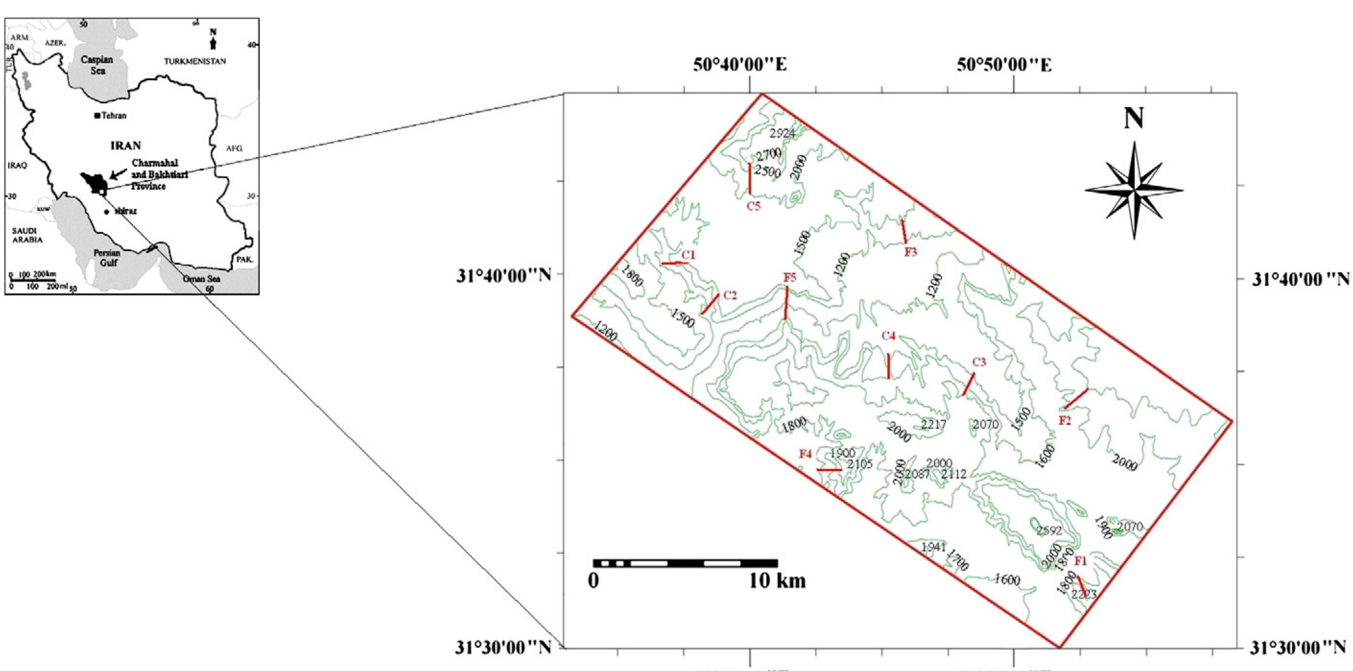

Fig. 1. Location of the study site and selected ten transects in the Lordegan district, west of Iran. (C1 to C5 for cultivated land, F1 to F5 for natural forest.).